Human Research Program Utilization Plan for the International Space Station

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NASA's Human Research Program (HRP) goal is to provide human health and performance countermeasures, knowledge, technologies, and tools to enable safe, reliable, and productive human space exploration. To meet that goal, NASA has analyzed the value and necessity of the International Space Station (ISS) to quantify the human health and performance risks for crews during exploration missions. Based on a set of exploration risks, the Human Research Program has defined a research and technology plan to address the risks. This plan is by 2016:

- to perform the research needed to identify and quantify risks to human health and performance
- to identify potential countermeasures
- to flight validate some of those countermeasures

By 2020, NASA's research on the ISS will validate the remaining countermeasures.

Introduction

NASA's Human Research Program has a comprehensive research plan that includes both flight and ground experiments and facilities. NASA has sharpened the human research focus on exploration missions to the moon and Mars. NASA's Human Research Program furthered its previously published analysis of the risks cataloged in the bioastronautics roadmap and determined the next steps in research and technology to quantify the risks and, wherever possible, reduce these risks to acceptable levels.

The International Space Station, as an orbiting, microgravity laboratory, provides an invaluable platform to secure knowledge, test countermeasures, and evaluate technologies important for the development and validation of risk mitigation techniques for exploration missions. The list of risks to be addressed on the ISS is given in table 1 below.

Risk of inability to adequately treat an ill or injured crew member
Risk of inadequate nutrition
Risk of inadequate food system
Risk of behavioral and psychiatric conditions
Risk of radiation carcinogenesis from space radiation
Risk of compromised extravehicular activity (EVA) performance and crew health due to inadequate EVA suit systems
Risk of accelerated osteoporosis
Risk of orthostatic intolerance during re-exposure to gravity
Risk of impaired performance due to reduced muscle mass, strength and endurance
Risk of reduced physical performance capabilities due to reduced aerobic capacity
Risk of therapeutic failure due to ineffectiveness of medication
Risk of performance errors due to poor team cohesion, performance, & psychosocial adaptation; inadequate selection/team composition & training
Risk of cardiac rhythm problems

Risk of intervertebral disc damage
Risk of crew adverse health event due to altered immune response
Risk of impaired ability to maintain control of vehicles and other complex systems
Risk of performance errors due to sleep loss, circadian desynchronization, fatigue, and work overload
Risk of operational impact of prolonged daily required exercise
Risk of unnecessary operational limitations due to inaccurate assessment of cardiovascular performance
Risk of bone fracture
Risk of renal stone formation
Risk of urinary tract dysfunction
Risk of impaired vision due to refractive visual changes during long duration space flight
Risk of adverse health effects due to exposure to hypoxic environments
Risk of adverse health effects due to prolonged exposure to elevated carbon dioxide levels

Table 1. Human Health and Performance Risks That Require ISS as a Research Platform for Resolution

The research plan for various risks is laid out as a progression of activities that are designed to address critical questions that must be answered to quantify the risk or develop mitigation strategies for the risk. The activities on ISS are essential for two reasons. First, because there is no effective ground-based analog to conduct the work on Earth, or secondly, the research activity needs the complete operational environment of space flight to validate the countermeasure or technology. The ISS is necessary to mitigate 25 of the 32 human health risks anticipated on exploration missions. Only those risks that require the ISS are described in this document.

Research is inherently non-linear. As NASA gains knowledge, understanding of the required approach changes. At the conclusion of the data gathering phase, researchers and the laboratories require up to one year to integrate and analyze the data. Subsequently, the results can be published and distributed. This document represents the best plan available at this snapshot in time. It would be impractical to assume a linear approach with respect to future research plans. This plan will be revised and updated based on consideration of new evidence gained, available resources, Constellation needs, and other driving schedule constraints.

A key cooperative partnership that the HRP uses to fill its mission is the National Space Biomedical Research Institute (NSBRI). The NSBRI[1] is a unique, non-profit scientific partnership with NASA committed to implementing the Vision for Space Exploration by providing practical, validated and effective solutions to support and maintain human health and performance during long-duration spaceflight. NSBRI engages academic, industrial and government researchers and educators, and the resources of the nation's leading biomedical research institutions, in a team-based effort to reduce the significant health risks associated with human space travel. The Institute's goal-directed, cost-efficient science, technology and research programs strongly impact both the safety of human space travel and the quality of life on Earth.
The HRP fills its mission through solicitations for research released yearly. Consistent with the National Space Biomedical Research Institute partnership intent, these solicitations are released

[1] For additional information regarding the NSBRI, www.**nsbri**.org/

jointly. Since specific investigation content has not yet been selected for downstream research activities of several risks, a general description of the nature of the research required and the relevancy of the research to the mission is currently defined.

NASA also fully intends to continue making efficient use of ISS resources through cooperative research with ISS Partners. NASA has been actively working with the European Space Agency (ESA), Russian Space Agency (RSA), Canadian Space Agency (CSA), and the Japan Aerospace Exploration Agency (JAXA) to ensure that research is coordinated to reduce overlap and take advantage of efficient research combinations.

The following sections describe first the risk and secondly the activities and a top-level schedule that require use of the International Space Station.

Risk of Inability to Adequately Treat an Ill or Injured Crew Member

Mission architecture limits the amount of equipment and procedures that will be available to treat medical problems. Additionally, not all medical conditions are treatable, given the limited resources, and some cases may go untreated.

Figure 1. Compact chemical analyzer.

To provide the broadest possible treatment capability, NASA will develop and test technologies using ISS to make the best possible use of limited mass, volume, power, and crew training. Analyzing bodily fluids (urine, blood, saliva) on the lunar surface will reduce launch/return mass/volume and provide the data near real-time in lieu of postflight results. A system to perform real-time analyses is necessary to meet these requirements. ISS will be important to establish that blood and urine analytical devices can be operated routinely in the microgravity environment.

Onboard advanced medical life support hardware will be required to treat the crewmembers on a regular and emergency basis. Technologies which are smaller, lighter, reliable, and user-friendly will be required to fit within the limited space of the spacecraft vehicles.

Currently on the ISS, the crewmember's source of additional oxygen if needed is the onboard oxygen tanks. The system provides 100% oxygen to the crewmember continuously, exceeding the spacecraft oxygen limit within minutes. For the smaller Constellation vehicles, a system which concentrates the oxygen within the cabin environment and provides the required concentration of oxygen to the crewmember will be necessary.

Figure 2. Lightweight trauma module.

Currently, limited quantities of Intravenous (IV) fluid are launched, stowed, and disposed of or returned to Earth (due to limited shelf life) on the International Space Station. These IV fluids take up valuable launch mass/volume, stowage volume onboard the ISS, and waste disposal volume. The ability to generate water for injection on-demand will minimize these resource impacts. The ISS will be used to flight validate this technology.

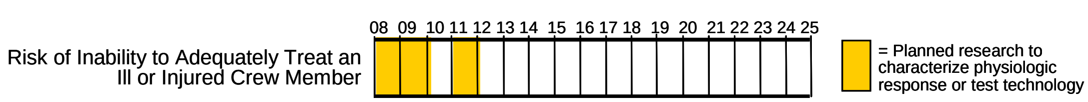
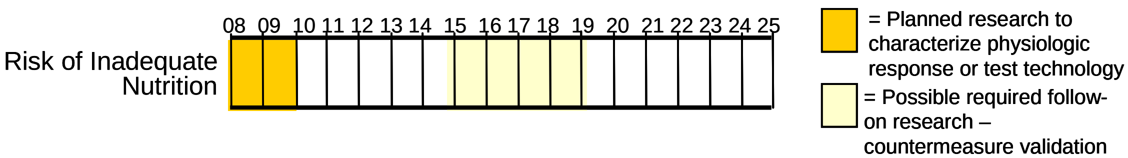


Figure 3. Sunita Williams loads the refrigerated centrifuge for the Nutrition experiment during Expedition 15.

Risk of Inadequate Nutrition

It is critical that crew members be adequately nourished before and during missions. The risks to adequate nutrition include misjudging nutritional needs; instability of nutrients during long-duration flight; inadequate fluids, macronutrients, micronutrients, vitamins, and other elements in the diet; and spaceflight induced changes in food absorption.

The ISS will be used to improve the nutritional content of the food when consumed, identify the variety, acceptability, and ease of use for long-duration missions, validate correct nutritional needs, and quantify the stability of nutrients during long-duration flight. ISS is required to ensure that the data represents space normal and for validation of potential countermeasures to inadequate nutrition. Flight validation of nutritional requirements will occur in 2015-2018 and updates to the nutrition standard will be made in 2018.

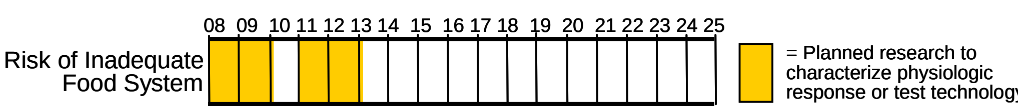


Risk of Inadequate Food System

If the food system does not adequately provide for food safety, nutrition, and acceptability, then crew health and performance and the overall mission may be adversely affected. Furthermore, if the food system uses more than its allocated mission resources, then total required mission resources may exceed capabilities, the mission deemed unfeasible, or allocation of resources to other systems may be unduly constrained.

The ISS will be used to validate a food system that provides safety, nutrition, and acceptability. It has always been understood that a safe food system is of extreme importance. Research areas include: stability of nutrients in the food system when exposed to the spaceflight environment and testing to determine the effects of isolation and length of mission on food acceptability. Additional studies will address the changes in the sense of taste and palatability of food in microgravity. All of the research will consider the affect of the technology on the mission resources such as mass, volume, power, and crew time.

Figure 4. Mikhail Tyurin, Thomas Reiter, Michael Lopez-Alegria share a meal.

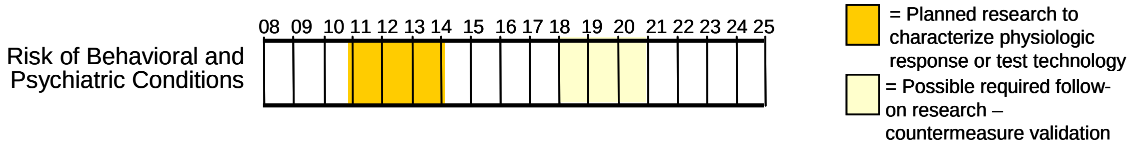


Risk of Behavioral and Psychiatric Conditions

Figure 5. Crewmembers participating in Journals use laptops to make entries of their thoughts for the day.

Behavioral issues are inevitable among groups of people, no matter how well selected and trained. Spaceflight demands can heighten these issues.

Use the ISS to emulate the transit environment to Mars to further characterize the risk of behavioral and psychiatric conditions that can develop during long-duration space travel so that validated and reliable tools that predict, detect, and assess this risk can be identified and/or developed, and the appropriate countermeasures can be developed.



Risk of Radiation Carcinogenesis from Space Radiation

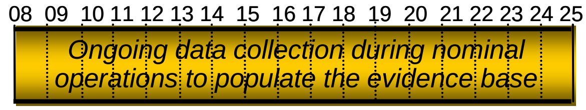
Figure 6. Radiation detection devices in the U.S. Lab.

Space radiation exposure increases cancer morbidity and mortality risk in astronauts. This risk may be influenced by other space flight factors including microgravity and environmental contaminants. Current space radiation risks estimates are based on human epidemiology data for X-rays and gamma-ray exposure scaled to the types and flux-rates in space using radiation quality factors and dose-rate modification factors, and assuming linearity of response. There are large uncertainties in this approach and experimental models imply additional detriment due to the severity of the phenotypes of cancers formed for the heavy ion component of the galactic cosmic rays compared to cancers produced by terrestrial radiation. A Mars mission may not be feasible (within acceptable limits) unless uncertainties in cancer projection models are reduced allowing shielding and biological countermeasures approaches to be evaluated and improved or unless mission durations are constrained.

Figure 7. mBAND method used to detect aberrations within a chromosome pair.

The ISS data collected during nominal operations (Medical Requirements Integration Document) (i.e. NOT research/experimental) will be used to update recommendations on Human System Standards and permissible exposure limits (PEL), provide scientific basis and recommendations on radiation protection requirements, update the Risk Assessment Model, baseline enhanced computational design tools for vehicle design assessment, and develop necessary countermeasures. Each ISS crewmember's medical history is followed and these data are used to update risk models.

Risk of Radiation Carcinogenesis from Space Radiation



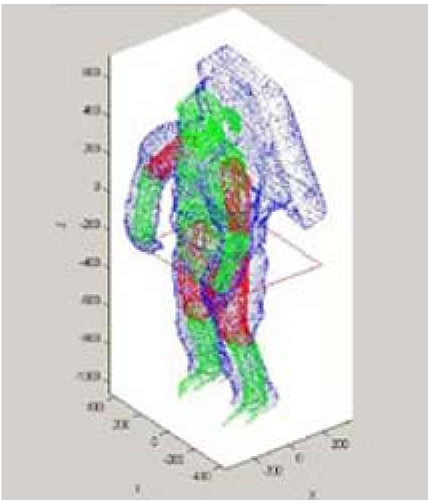


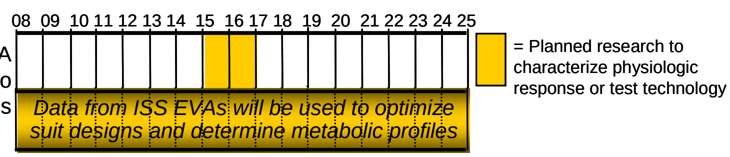
Figure 8. EVA Suit Design to understand effects of suit weight, center of gravity, and pressure on performance and metabolic cost.

Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems

Improperly designed extravehicular activity (EVA) suits can result in the inability of the crew to perform as expected, and can cause mechanical and decompression injury. Suit developers must fully understand the impact of the suit design on crew performance and health to ensure properly designed mobility, pressures, nutrition, life support, etc.

The information from ISS-based EVAs will be used to identify suit-induced trauma and entered into a searchable database to track suit injury. In addition, the ISS data will be used to determine mission metabolic profiles and to quantify consumables during operations. Data from each ISS extravehicular activity (EVA) will be used to optimize suit designs and determine metabolic profiles.

Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems



Risk of Accelerated Osteoporosis

Bone mineral loss occurs in microgravity due to unloading of the skeletal system, with average loss rates of approximately 1% per month. It is unclear whether this bone mineral density loss will stabilize at a lower level, or continue to diminish. It is unknown if fractional gravity, present on the moon and Mars, would mitigate the loss. Greater understanding of the mechanisms of bone demineralization in microgravity is necessary to frame this risk, as well as to understand how current and future osteoporosis treatments may be employed. This risk deals specifically with the likelihood of developing post-mission osteoporosis.

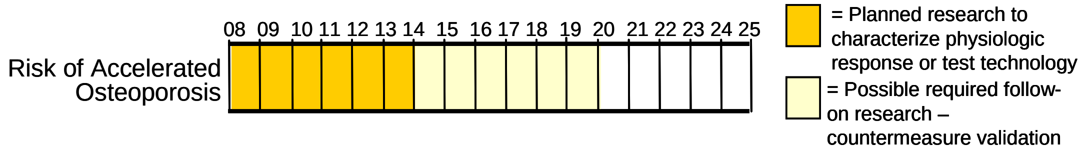
Figure 9. Bone Health Monitoring.

ISS is required to gather the space normal data needed to define long term recovery of bone mineral density. Specifically, ISS flight studies will be performed in 2008-2012 and the results used to validate and/or update the existing bone health standards in 2013. If results determine that a bone recovery countermeasure is needed, the ISS will be used to validate ground-based studies for countermeasure development. The ISS will enable the HRP to deliver a bone recovery countermeasure to mission operations in 2020. These activities are designed to mitigate a risk for long-duration Lunar and Mars missions and are conducted on board ISS prior to the unavailability of the ISS as a Mars transit analog.

Validated methods and technologies to analyze bone turnover for use in spaceflight applications is required. Flight studies will be performed in 2011-2014 to validate the methodology and novel technologies in a spaceflight environment using the ISS.

To determine whether bisphosphonates, in conjunction with the routine inflight exercise program, protects ISS crewmembers from the regional decreases in bone mineral density documented on previous ISS flights, two studies will use the ISS. These studies also will document the return to normal bone remodeling postflight in crewmembers who took bisphosphonates.

ISS studies also will be used to validate a nutrition countermeasure to maintain bone structure and strength during long-duration spaceflight in the 2013-2016 timeframe for delivery to mission operations by 2016.

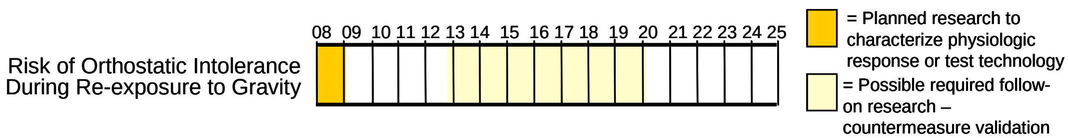


Risk of Orthostatic Intolerance During Re-exposure to Gravity

Postflight orthostatic intolerance, the inability to maintain blood pressure while in an upright position, is an established, space-related medical problem. Countermeasures have been successfully identified and implemented (fluid loading, compression garments) or are being evaluated (Midodrine & others).

Figure 10. View of astronaut John L. Phillips during a tilt table test, in Baikonur, Kazakhstan.

A number of countermeasures are under study for eliminating or minimizing the risk of orthostatic intolerance upon landing. The ISS is required to flight validate these countermeasures, such as the efficacy of Midodrine in reducing the incidence and/or severity of orthostatic hypotension in returning astronauts by 2009. Other studies include the use of pressure garments and pharmaceutical countermeasures; both of which will use the ISS for validation studies in the spaceflight environment.

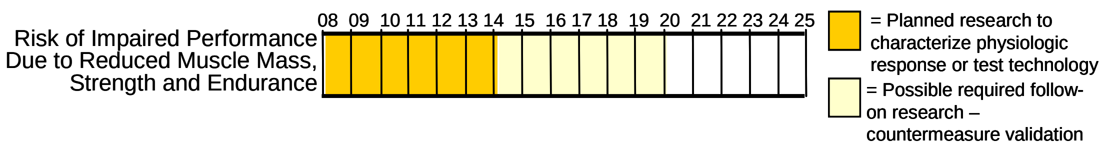


Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance

Figure 11. William McArthur hooks up the squat harness for the resistive exercise device.

There is a growing research database which suggests that skeletal muscles, particularly postural muscles of the lower limb, undergo atrophy and structural and metabolic alterations during space flight. However, the relationships between inflight exercise, muscle changes, and performance levels are not well understood.

ISS will be required to validate optimized countermeasures and hardware (e.g., resistance exercise device, treadmill, cycle ergometer). Optimized countermeasures are those that need minimal exercise to free crewmember time for other tasks required for mission success, need minimal volume and hardware to maintain muscle mass, strength and endurance. The ISS will be used to validate the functional task tests that measure physiological decrements in crewmembers.

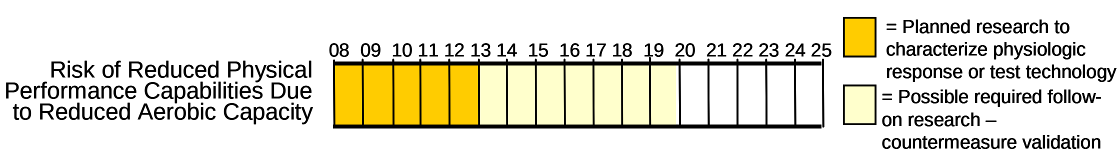


Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity

Figure 12. Sunita Williams sets up O_2 uptake measurement.

Astronauts' physical performance during a mission, including activity in microgravity and fractional gravity, is critical to mission success. In addition to reduced skeletal muscle strength and endurance, reduced aerobic capacity may put mission success at risk. Sustained sub-maximal activities (even walking on a planetary surface) could become difficult to perform given large enough decrements in aerobic capacity.

The ISS will be used to measure aerobic capacity (VO_2 max) and cardiac output during and after long term space flight. In addition, the ISS will be used to optimize and subsequently to validate prescriptions for exercise volumes, regimens, and equipment. The ISS will be used to optimize and validate lunar tasks and their physical performance costs.



Risk of Therapeutic Failure Due to Ineffectiveness of Medication

Based on subjective reports, drugs are effective during space flight. Risk is related to record keeping of medication use, efficacy, and side effects. Additional risk results if medications are found to be ineffective or if space flight affects drug stability.

The ISS will be used to perform drug efficacy studies. The ISS is required for proper radiation doses on pharmaceutical samples to identify pharmaceutical preparations at risk for degradation which are used by astronauts during space missions and to characterize degradation profiles of the unstable formulations after exposure to the ISS environment. The ISS is also used to identify microgravity-related changes in pharmacokinetics. If an issue is found, the ISS will be used to test the appropriate countermeasures.

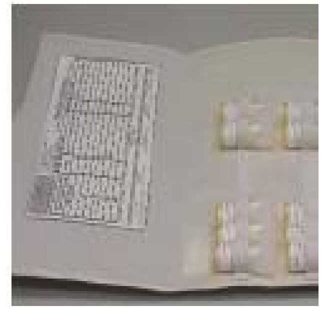
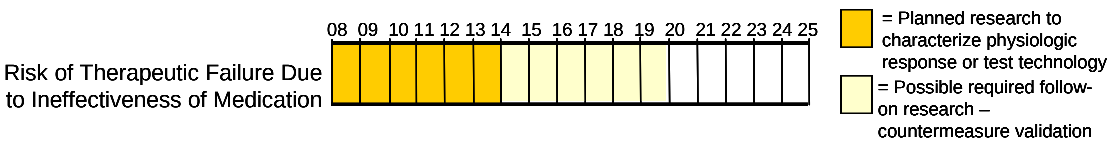


Figure 13. Vials to collect saliva samples to study the impact from side-effects of promethazine, a medication taken by astronauts to prevent motion sickness.

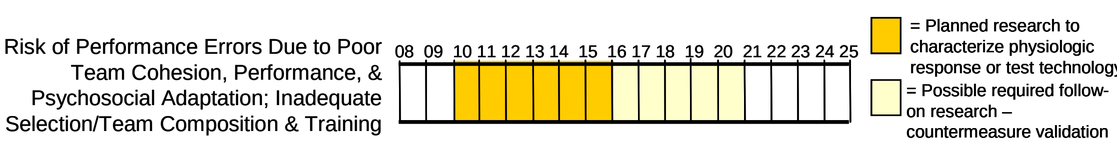


Risk of Performance Errors Due to Poor Team Cohesion, Performance, & Psychosocial Adaptation; Inadequate Selection/Team Composition & Training

Risk of performance errors due to poor team cohesion and performance, inadequate selection/team composition, inadequate training, and poor psychosocial adaptation have not been determined.

The ISS will be used for flight validation of methods and technologies that monitor individual and crew for performance errors due to poor team cohesion and performance, inadequate selection/team composition, inadequate training, and poor psychosocial adaptation. These include facial recognition monitoring technology, voice acoustic technology, communications technology, and conflict management technology. In addition, the ISS crews will be used to collect data and gather evidence on the effects of increased autonomy on group cohesion and performance and the most effective methods for mitigating stress and deteriorated morale to optimize performance (exercise, food, privacy, entertainment).

Figure 14. STS-120 Doug Wheelock, Scott Parazynski, and Paolo Nespoli in Discovery's middeck.

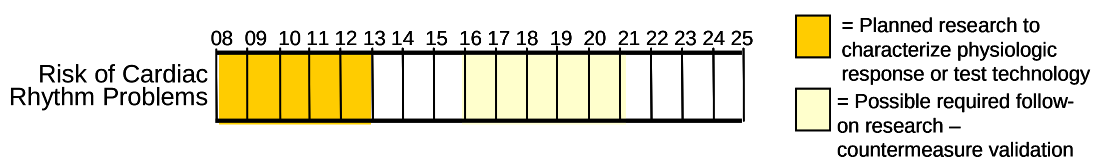


Risk of Cardiac Rhythm Problems

Figure 15. Leroy Chiao and Yuri Shargin on mechanized tilt tables used to condition the crewmembers' cardiovascular system.

Heart rhythm disturbances have been seen among astronauts. Most of these have been related to cardiovascular disease, but it is not clear whether this was due to pre-existing conditions or effects of space flight. It is hoped that advanced screening for coronary disease has greatly mitigated this risk. Other heart rhythm problems, such as atrial fibrillation, can develop over time, necessitating periodic screening of crewmembers' heart rhythms. Beyond these terrestrial heart risks, some concern exists that prolonged exposure to microgravity may lead to heart rhythm disturbances. Although this has not been observed to date, further surveillance is warranted.

ISS is required as the Mars transit analog for initial work to define "space normal" and subsequent countermeasure validation. Specifically scientists will use the ISS to measure the time course of changes in cardiac structure and function over six months of spaceflight. They will define the potassium, magnesium, and phosphorus changes in relation to cardiovascular issues. If an issue is found, the ISS will be required to validate countermeasures.



Risk of Intervertebral Disc Damage

Evidence from medical operations indicates that astronauts have a higher incidence of intervertebral disc damage than the general population. Extended exposures to microgravity (and possibly fractional gravity) may lead to an increased risk of spinal nerve compression and back pain.

Additional evidence will be gathered from ISS crewmembers in order to establish whether the lengthening of the spine exacerbates the risk for intervertebral damage with loading. The ISS will be used to determine the extent of this problem and guide design of re-entry and postflight protocols as well as future re-entry spacecraft. If significant issues are found, the ISS will be required to validate countermeasures. In addition, ISS is required as the Mars transit analog for countermeasure validation.

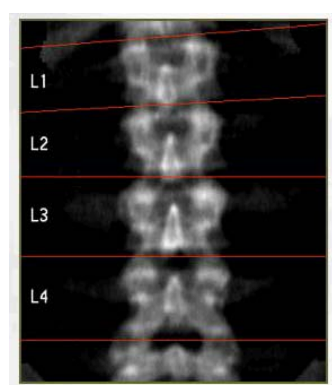
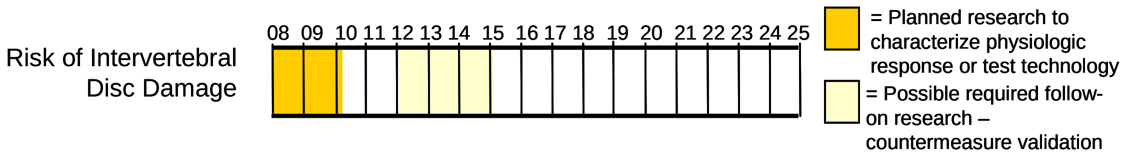


Figure 16. Human spine.

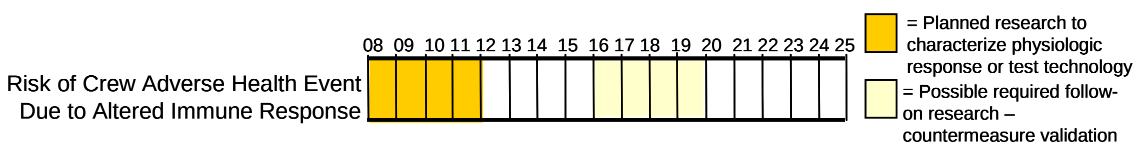


Risk of Crew Adverse Health Event Due to Altered Immune Response

Human immune function is altered in- and postflight, but it is unclear if this change leads to an increased susceptibility to disease. Reactivation of latent viruses has been documented in crewmembers, though this reactivation has not been directly correlated with the immune changes or with observed disease.

Figure 17. The Immune kit contains all the items the crew needs for taking blood samples.

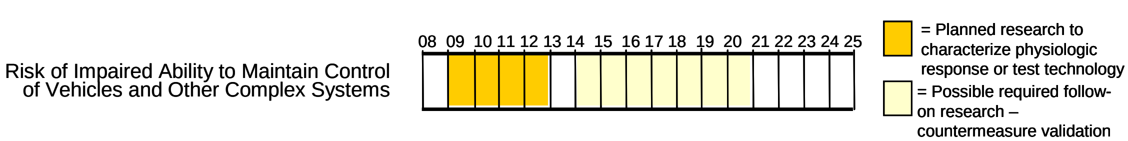
ISS is required to investigate and validate the magnitude of immunosuppression as a result of space flight to ensure that the data represents space normal. The ISS will be used to develop and validate an immune monitoring strategy consistent with operational flight requirements and constraints. There are no procedures currently in place to monitor immune function or its effect on crew health although immune dysregulation has been demonstrated during space flight. The ISS will be used to validate potential countermeasures, if an issue is found.



Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems

It has been shown that long duration space flight alters sensorimotor function which manifests as changes in locomotion, gaze control, dynamic visual acuity, and perception. These changes have not been specifically correlated with real time performance decrements. The possible alterations in sensorimotor performance are of interest for Mars missions due to the prolonged microgravity exposure during transit followed by landing tasks. This risk must be better documented and changes must be better correlated with performance issues.

Since Mars operational scenarios are still to be determined, the ISS should be used to gather the data required to define the research that might be needed to enable future Mars mission operations. This data includes the remote manipulator system, Space Station Remote Manipulator System, docking, glove box operations, Soyuz landings, and performance related to neurosensory dysfunction. If countermeasures for Mars missions are warranted, the ISS will be required as the Mars transit analog for countermeasure validation.



Risk of Performance Errors Due to Sleep Loss, Circadian Desynchronization, Fatigue, and Work Overload

Figure 18. ESA's Paolo Nespoli rests in his sleeping bag in the Harmony node of ISS.

Fatigue occurs during spaceflight and may jeopardize health and performance. This risk may be influenced by artificial and transmitted light exposure, individual vulnerability to sleep loss and circadian dynamics, and work/sleep schedules. Efforts are needed to improve sleep hygiene, and to identify and improve conditions that interfere with sleep quality.

Use the ISS to assess artificial and transmitted light exposure on performance, to quantify individual vulnerability to sleep loss, circadian dynamics, work/sleep schedules, and the effects of sleep/wake medications. The ISS will be used to collect data and subsequently validate a self-assessment tool for cognitive function and fatigue; light therapy for phase shifting, alertness and mood disorders; and other means to improve sleep quality and reduce fatigue. The ISS is required because of sleep-related issues associated with microgravity, and to ensure that the tools and methods are appropriate for the spaceflight environment.

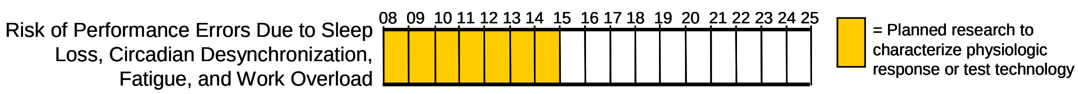


Figure 19. Michael Lopez-Alegria exercises on the CEVIS.

Risk of Operational Impact of Prolonged Daily Required Exercise

Muscle atrophies in microgravity and strength decreases. Currently, significant daily time is devoted to crew exercise. Making the exercise more efficient may allow similar beneficial effects to be achieved more simply, and in shorter time, which would provide more crew time for operational support.

The ISS is needed to benchmark crew strength requirements and test exercise equipment and regimens against these benchmarks. This will promote the development of more efficient, yet equally safe, exercise regimens. The ISS is required to validate instrumentation (advanced resistive exercise device), optimized countermeasures (VO^2 max), and exercise devices for exploration.

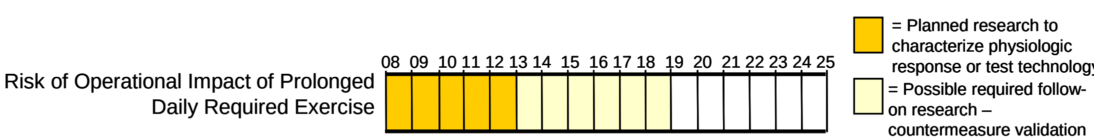
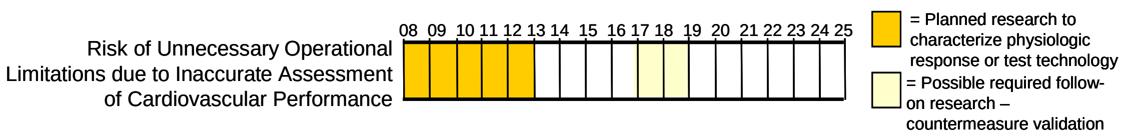


Figure 20. Clayton Anderson with a continuous blood pressure device for the cardiovascular and cerebrovascular control on return from the ISS

Risk of Unnecessary Operational Limitations due to Inaccurate Assessment of Cardiovascular Performance

Current inflight indicators of cardiac performance may not accurately reflect astronauts’ cardiovascular performance. Making operational decisions based on inaccurate cardiac performance measures may unnecessarily restrict crewmembers for critical activities or, more seriously, could subject crewmembers to activities for which they are not physically prepared. Accurate measurement of crewmember aerobic capacity can eliminate this risk.

ISS is required as the Mars transit analog for initial work and countermeasure validation for a number of cardiovascular studies. For example a countermeasure to protect cardiac function, to measure aerobic capacity (VO^2 max) and cardiac output. If an issue is discovered, the ISS will be used to develop the appropriate countermeasures.



Risk of Bone Fracture

Bone mineral loss occurs in microgravity due to unloading of the skeletal system, with average loss rates of approximately 1% per month. It is unclear whether this bone mineral density will stabilize at a lower level, or continue to diminish. It is also unknown if fractional gravity, present on the moon and Mars would mitigate the loss. This level of bone loss does not create an unacceptable risk of fractures for ISS missions, but longer missions could create higher fracture risk. The risk of fracture during a mission cannot be accurately estimated until mechanisms and probabilities of bone overloading during the missions are understood. This risk deals specifically with the risk of one fracture during an exploration mission.

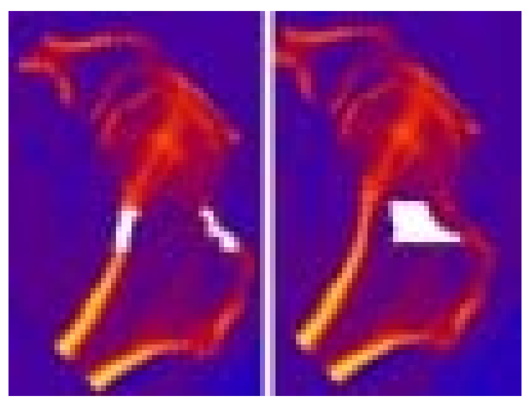
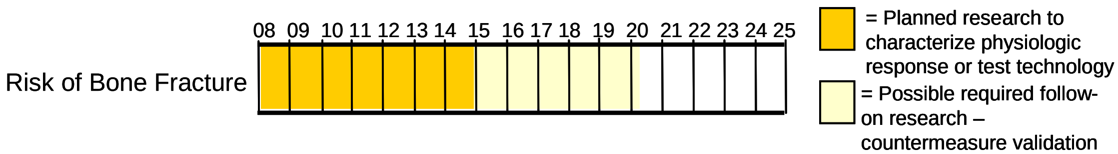


Figure 21. QCT 1 mm thick section through mid-frontal plane of the hip; regions of evaluation in white.

Post mission data will be gathered from ISS crews to validate and/or update the current Space Human Health bone standard.

Validated technologies to monitor changes in bone quality for use in spaceflight applications will be delivered. After initial ground-based studies, follow-on ISS studies will be used to flight-validate the technology.

A flight study will be conducted to assess spine health pre and post ISS missions. The initial measures will determine if there are vertebral compression fractures in returning crew.

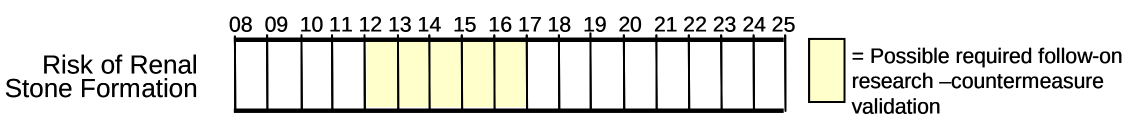


Risk of Renal Stone Formation

Kidney stone formation and passage has the potential to greatly impact mission success and crewmember health for long duration missions. Alterations in hydration state (relative dehydration) and bone metabolism (increased calcium excretion) during exposure to microgravity may increase the risk of kidney stone formation and it is unclear which mitigation strategy would be the most effective.

Figure 22. Thomas Reiter on ISS processes samples for the renal stone investigation.

This ISS investigation will take the next step in understanding the stone-forming risk crewmembers experience during and after space flight, and analyze the ISS test data to determine the efficacy of potassium citrate as a countermeasure to reduce this risk. Based on the known increased risk crewmembers experience, it is important to develop and test countermeasures to reduce or alleviate this risk. ISS is required as the Mars transit analog for countermeasure validation if countermeasures other than potassium citrate are needed.



Risk of Urinary Tract Dysfunction

Multiple cases of urinary retention and subsequent urinary tract infections have been observed during short duration space flight, chiefly among females. It is not clear why exposure to microgravity adversely affects the functioning of the urinary tract nor is the clinical management of these cases in microgravity understood.

NASA will perform data mining activities to determine known issues associated with urinary tract infections. If issues exist, countermeasures will be developed and flight validation studies conducted on ISS.

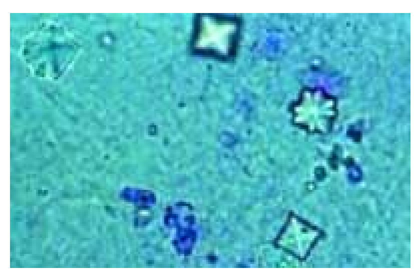
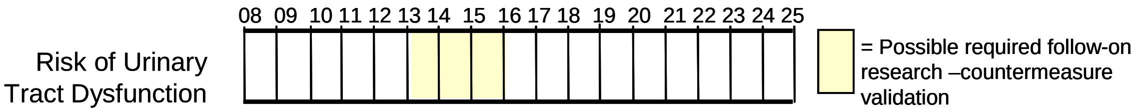


Figure 23. Micrograph of calcium oxalate crystals in urine which can develop to form renal stones.

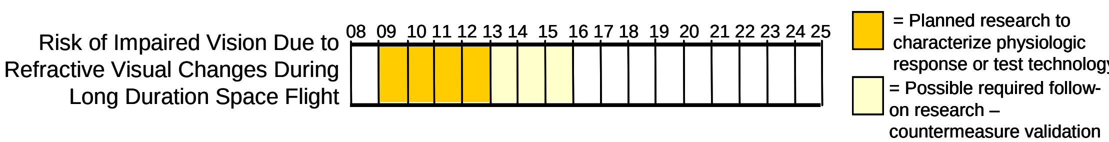


Risk of Impaired Vision Due to Refractive Visual Changes During Long Duration Space Flight

Figure 24. Refractive visual changes.

Significant changes in visual refraction have been documented among ISS crewmembers. These changes appear to be due to naturally occurring, accommodative changes that may be exacerbated by the small volume of spacecraft cabins. Vascular engorgement of retinal support layers also appears to play a role.

The ISS will be the platform used to identify risk factors affecting crewmembers' vision, underlying pathophysiology, and mitigation strategies for maintaining crew vision during long-duration missions. If necessary, the ISS will then be used to validate the countermeasures defined for mitigating impaired vision.



Risk of Adverse Health Effects Due to Exposure to Hypoxic Environments

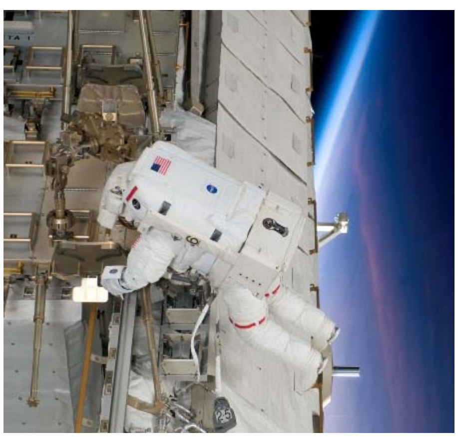
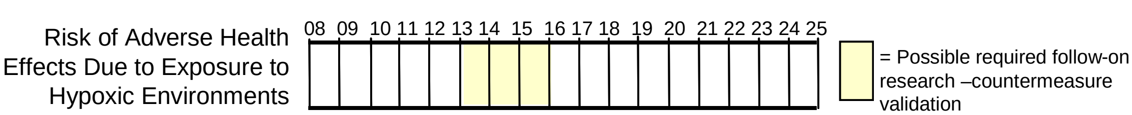


Figure 25. Clayton Anderson against the blackness of space and Earth's horizon.

Spacecraft designers strive to maintain a normal terrestrial atmosphere for crewmembers; however, frequent extravehicular activities (EVA) necessitate decreasing the atmospheric nitrogen levels to decrease the risk of decompression sickness. Decreasing nitrogen partial pressure without decreasing oxygen partial pressure creates a significant fire risk. Concerns exist whether crew performance could be adversely affected if cabin oxygen pressures are decreased.

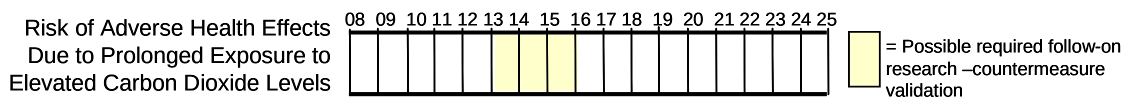
The ISS will be used to develop and flight-validate countermeasures if data mining activities show that there are known issues associated with hypoxic environments.



Risk of Adverse Health Effects Due to Prolonged Exposure to Elevated Carbon Dioxide Levels

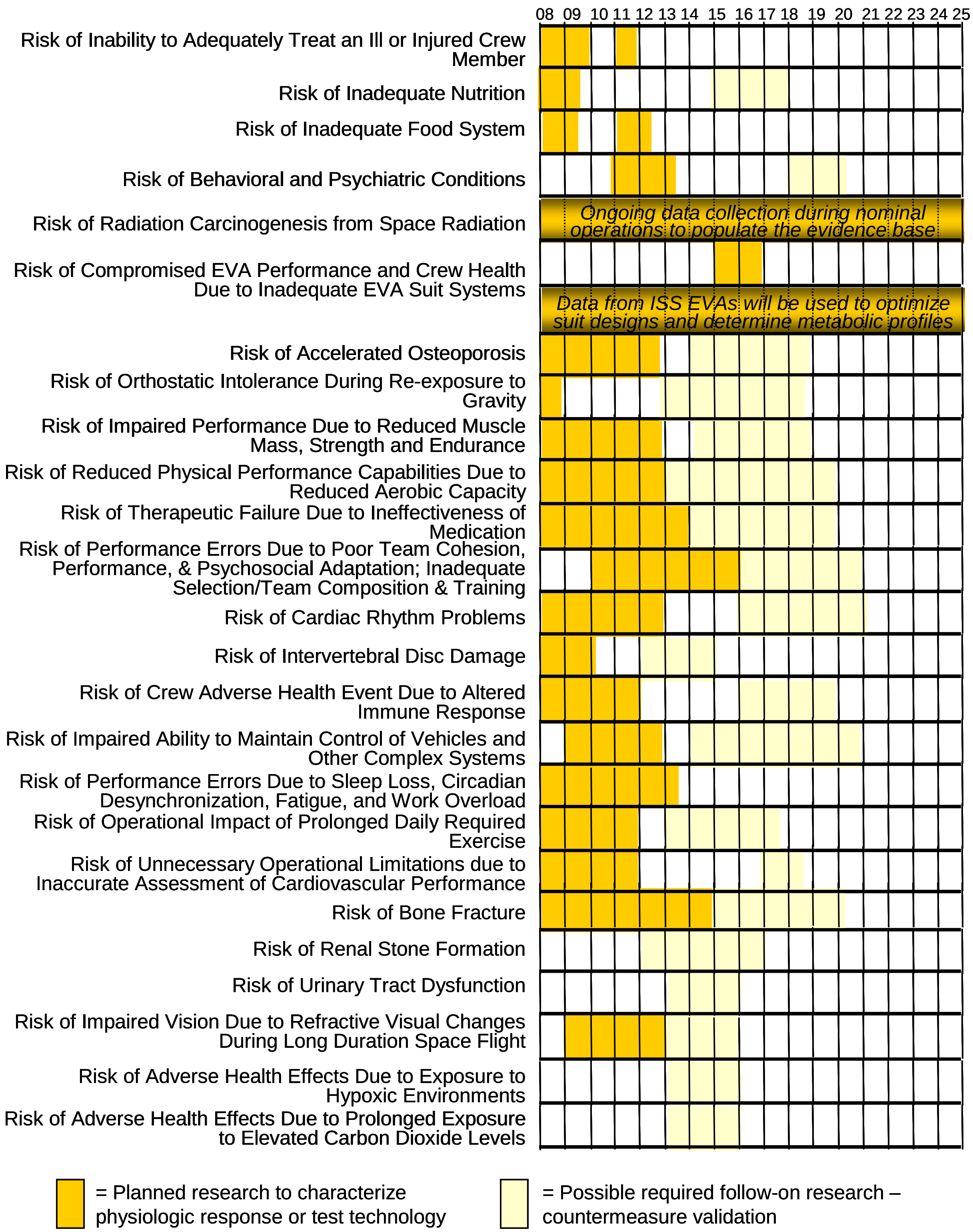
Available scrubbing technologies cannot lower cabin carbon dioxide (CO_2) levels to terrestrial atmospheric concentrations. Frequent repairs of complex scrubbing equipment have led to elevated CO_2 levels on multiple occasions. Crews often complain of symptoms that could relate to elevated CO_2 levels. It is unclear how chronic exposure to elevated CO_2 levels affects human health. More research is necessary

Normal levels of carbon dioxide (CO_2) on board the ISS are at 5mm mercury. When the CO_2 levels get above 5mm of mercury, the crew complains of symptoms (i.e., headaches, malaise, and general poor health). Most of the data associated with this risk is anecdotal. The ISS will be used to determine if the CO_2 levels are chronically just below the symptom levels (5mm mercury) and if so the effect on the body. If issues exist, the ISS will be used to flight validate countermeasures to elevated CO2 levels.



Summary

In summary, the ISS remains an invaluable asset in addressing human risks sufficiently to enable NASA to safely proceed with lunar, Mars, and other interplanetary missions. It will be used through 2020 to complete the studies necessary to understand the severity of certain risks, to gather evidence to quantify the risks, and to complete the development of key countermeasures. The ISS research allows validation of techniques and technologies needed for the moon and particularly the transit phase of a Mars mission.


08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Risk of Inability to Adequately Treat an Ill or Injured Crew Member
Risk of Inadequate Nutrition
Risk of Inadequate Food System
Risk of Behavioral and Psychiatric Conditions
Risk of Radiation Carcinogenesis from Space Radiation
Ongoing data collection during nominal operations to populate the evidence base
Risk of Compromised EVA Performance and Crew Health Due to Inadequate EVA Suit Systems
Data from ISS EVAs will be used to optimize suit designs and determine metabolic profiles
Risk of Accelerated Osteoporosis
Risk of Orthostatic Intolerance During Re-exposure to Gravity
Risk of Impaired Performance Due to Reduced Muscle Mass, Strength and Endurance
Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity
Risk of Therapeutic Failure Due to Ineffectiveness of Medication
Risk of Performance Errors Due to Poor Team Cohesion, Performance, & Psychosocial Adaptation; Inadequate Selection/Team Composition & Training
Risk of Cardiac Rhythm Problems
Risk of Intervertebral Disc Damage
Risk of Crew Adverse Health Event Due to Altered Immune Response
Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems
Risk of Performance Errors Due to Sleep Loss, Circadian Desynchronization, Fatigue, and Work Overload
Risk of Operational Impact of Prolonged Daily Required Exercise
Risk of Unnecessary Operational Limitations due to Inaccurate Assessment of Cardiovascular Performance
Risk of Bone Fracture
Risk of Renal Stone Formation
Risk of Urinary Tract Dysfunction
Risk of Impaired Vision Due to Refractive Visual Changes During Long Duration Space Flight
Risk of Adverse Health Effects Due to Exposure to Hypoxic Environments
Risk of Adverse Health Effects Due to Prolonged Exposure to Elevated Carbon Dioxide Levels
= Planned research to characterize physiologic response or test technology
= Possible required follow-on research – countermeasure validation